An Adaptive Blended Learning Model for the Implementation of an Integrated Medical Neuroscience Course During the Covid-19 Pandemic

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The implementation of an integrated medical neuroscience course by technologically pivoting an in-person neuroscience course to online using an adaptive blended method may provide a unique approach for teaching a medical neuroscience course during the Covid-19 pandemic. An adaptive blended learning method was developed in response to the requirements necessitated by the Covid-19 pandemic. This model combined pedagogical needs with digital technology using online learning activities to implement student learning in a medical neuroscience course for year one medical students. This approach provided medical students with an individually customized learning opportunity in medical neuroscience. The students had the complete choice to engage the learning system synchronously or asynchronously and learn neuroscience materials at different locations and times in response to the demands required to deal with the pandemic. Students' performance in summative and formative examinations of the adaptive blended learning activities were compared with the previous performance obtained the previous year when the contents of the medical neuroscience course were implemented using the conventional "face-to-face" learning approach. While the cohort of our students in 2019 and 2020 changed, the contents, sessions, volume of material, and assessment were constant. This enabled us to compare the results of the 2019 and 2020 classes. Overall, students' performance was not significantly different between the adaptive blended learning and the in-person approach. More students scored between 70% and 79% during the adaptive blended learning compared with in-class teaching, while more students scored between 80% and 89% during the in-person learning than during the adaptive blended learning. Finally, the percentage of students that scored >90% was not significantly different for both Years 2019 and 2020. The adaptive blended learning approach was effective in enhancing academic performance for high-performing medical students. It also permitted the early identification of underachieving students, thereby serving as an early warning sign to permit timely intervention. Anat Sci Educ 14: 699–710. © 2021 American Association for Anatomy.

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INTRODUCTION

An important evolutionary process in the implementation of a medical education curriculum has involved combining traditional face-to-face learning with digital technology to create a blended learning approach as a new paradigm of delivering an integrated medical curriculum (Micheal and Marjadi, 2018; Engel et al., 2019; Chen et al., 2020). Blended learning has helped to eliminate the problem of geographical

proximity by leveraging technology to provide an alternative content delivery option for medical students. Blended learning has been described as merging face-to-face instruction with technology-mediated instruction, where all participants in the learning process are separated by distance most of the time (Micheal and Marjadi, 2018; Swito et al., 2018; Isayeva et al., 2020). Different forms of blended learning have involved different methods of pedagogy, including distributed, decentralized, and hybrid learning approaches (Saqr et al., 2017; Shang and Liu, 2018). Although these learning pedagogies have had subtle differences, they all address the problem of geographical distance with a focus on instructor-to-learner interaction (Saqr et al., 2017). Various models of blended learning have presented different approaches (Wangwattana and Lertnattee, 2019). An important factor involved in the choice of a specific model is that the model chosen meets the particular needs of medical students at a particular time, especially in the context of geographical location and the particular demands required when responding to a pandemic (Brown, 2016). In this context, blended learning may be viewed as a continuum of a form of distance education, fully online with or without classroom teaching (Bates, 2015). This implies that there should be adaptability in blended learning approaches (Graham, 2013; Bates, 2015; Neborsky et al., 2020). One approach involves the use of digital technology, thus providing a virtual interface that replaces the face-to-face interaction, and then combines the virtual communication with online activities to implement a medical neuroscience course designed to meet the requirements demanded when responding to a pandemic. This approach uses adaptive blended digital learning, which utilizes online learning as the mainstay of content delivery combined with technology infrastructure to support the online activities. The resulting approach has been designed to meet the needs of medical students under specific circumstances (Gurung et al., 2016; Maza et al., 2016; Khalil et al., 2018; Muresanu and Buzoianu, 2020).

Adaptive learning has been used to provide an individualized learning experience with technologies and represents one fundamental quality of effective learning (Bransford et al., 2000). Therefore, adaptive learning has focused on using what is known about medical students as learners in an integrated or traditional curriculum to systematically alter the flow of learning activities to suit their learning needs at a particular time (German and Gallego, 2016; Hernández and Ramírez, 2016; Tashiro and Hebeler, 2019; Wangwattana and Lertnattee, 2019; Clark and Kaw, 2020). There is a high prevalence and acceptance of digital learning resources by medical students (Gutmann et al., 2015; Scott et al., 2018). A medical school curriculum that builds on this strength in digital technology will provide a superior learning experience (Jameson et al., 1996; Marchevsky et al., 2003; McCutcheon et al., 2015). Moreover, medical students are accustomed to working independently at their own pace (Brechtel et al., 2018; Micheal and Marjadi, 2018; Swito et al., 2018; Brechtel et al., 2019; Isayeva et al., 2020). This approach has provided an individualized, customized, fluid schedule allowing medical students to use different active learning strategies (Ramklass, 2014; Protsiv et al., 2016). Therefore, knowledge of what is known about the skills of medical students in an integrated medical curriculum could subsequently be used to develop and further refine adaptive blended learning activities. While it is challenging to implement an in-person medical neuroscience course during the Covid-19 pandemic, maintaining the same content, sessions, and volume

of materials that have been utilized during previous in-person classroom settings are even more challenging.

Before the onset of Covid-19, the implementation of a remote anatomy course was always an administrative decision or that of the anatomy faculty due to changes in pedagogy. This is because anatomy education has been historically an in-person discipline, and few programs have successfully implemented anatomy courses in a remote learning format. This limits the amount of supporting evidence concerning their utility and reproducibility (Attardi et al., 2018). Therefore, anatomical sciences represent a foundational discipline for many health science-related professional programs with the typical in-person lecture and laboratory format known to be important for a complete anatomical educational experience for medical students (Farkas et al., 2016). Because of the paucity of literature on the remote learning of anatomy, anatomy educators were challenged to determine the best way to teach anatomy remotely during the global pandemic (Pather et al., 2020; Harmon et al., 2021; Lemay et al., 2021). Moreover, some anatomy educators saw the Covid-19 pandemic as an opportunity to broaden the scope of their teaching methods (Longhurst et al., 2020). This led to several ideas including transitioning from conventional "face-to-face" learning as practiced in "brick and mortar" schools to the use of an "adaptive blended learning pedagogy." This provided a paradigm shift in the implementation of anatomy and neuroanatomy laboratory activities and teaching of the medical neuroscience course during a pandemic. While it is understandable that traditional classroom curricula are not designed to be implemented online (Harden and Hart, 2002; Payne, 2011; Green and Whitburn, 2016) especially during a pandemic, an adaptive blended learning approach may provide digitalized virtual or live interactions that can effectively replace the face-to-face option to implement a medical neuroscience course (Sandrone and Schneider, 2020). This is partly due to the fact that medical students benefit from adaptability in the use of digital learning platforms (Pereira et al., 2007; Winston et al., 2010; Ramklass, 2014; El Sadik and Al Abdulmonem, 2021) that are available in an integrated medical curriculum. This provides a unique opportunity to develop an adaptive blended learning pedagogy for the implementation during times that require that students be distanced from one another, such as during the Covid-19 pandemic.

Digital technology is the cornerstone of an integrated medical neuroscience course (Geoghegan et al., 2019; Ruisoto and Juanes, 2019), it also represents the backbone of an adaptive blended learning pedagogy. A strong background of faculty members with a digital platform for delivering an integrated medical neuroscience course that includes real-time interaction with medical students may enhance the efficient implementation of a medical neuroscience course using an adaptive blended learning model. Although the cohort of our students in the Year 2019 for the in-person and Year 2020 for the adaptive blended learning was different, the contents, sessions, volume of material, and assessments were constant. Online activities and digital technology were central to the adaptive blended approach; and, the in-person instruction allows for a collaborative learning experience. This provided the opportunity to test the hypothesis that students' performance in in-person and adaptive learning will be different and that in-person learning may be more effective in enhancing students' performance because of the collaborative learning experience that enables students to interact during learning activities. This study describes the implementation of a medical neuroscience course

using an adaptive blended learning model with no face-to-face interactions between faculty and students. Digital technology was used to facilitate virtual interaction. Student performance in the adaptive blended learning activities was compared with previous performance when the contents of the medical neuroscience course were implemented in the conventional "face-to-face" learning, or in-person classroom activities. This enabled determining whether the in-person classroom or traditional "brick-and-mortar" learning enhanced academic performance when compared with an adaptive blended learning approach to teaching an integrated medical neuroscience course in the time of a global pandemic.

MATERIALS AND METHODS

Student Demographics

A total of 102 medical students across both years (Years 2019, n = 102 and 2020, n = 102) registered for the Neuroscience course. For the 2019 class, about 62% of the class were female, and 38% were male. For the 2020 class, 55% were female and 45% were male. The average age for both classes was 23.0 (SD ± 0.78). The average percentile of Medical College Admission Test (MCAT) score for those admitted in the Year 2019 was 72, while that of 2020 was 73. For medical students admitted in the Year 2019, the average GPA was 3.66, while for those of the Year 2020 the average was 3.65. This study was approved by the University of South Carolina Institutional Review Board of the Health Institutional Committee for ethics.

Description of the Medical Neuroscience Course

At the University of South Carolina-Greenville, the integrated medical neuroscience course is taught in the freshman year of medical school. Clinical cases form the foundation of this course, permitting learning the structures and function of the nervous system in an integrated clinical context. In the implementation of the course, weekly topics were organized into different themes including the anatomical and functional organization of the nervous system for week 1, and structural and functional correlates of neuronal activity for week 2. In week 3, the vascular supply of the nervous system was discussed, while the focus of week 4 emphasized motor and sensory systems. Apart from the weekly integration at the level of each session, the general integration of basic neuroscience concepts with clinical presentations was dealt with in week 5. The thematic organization of the course into weekly themes enabled the use of clinical cases as a template to provide the clinical context and relevance for the neuroscience concepts based on learning objectives that supported the learning goals of the course (Table 1). For example, the students were given a clinical case of a patient presenting with a prolactinoma that resulted in a bitemporal heteronymous hemianopsia. This case discussed the classic clinical presentation of pituitary prolactinoma in terms of signs and symptoms of hormone excess (which can result in erectile dysfunction in males or amenorrhea in females as well as galactorrhea). As the tumor grows, it can compress the optic chiasm causing visual disturbances. The classic presentation is that of bitemporal heteronymous hemianopsia patient. A significant part of the discussion focused on the spatial mechanism of how a large tumor compresses the optic chiasm, disturbing the blood supply of the crossing optic nerve fibers, and thereby affecting their ability to send visual information from both eyes. For, example, sometimes a pituitary tumor affects the optic nerve on just one side. In other cases, it affects the optic chiasm, where the optic nerves from each eye merge. This allows students to associate the content, neuroanatomy, with how they will use it in a clinical setting, which potentiates motivation and retention.

Further students learned that when a pituitary tumor presses upon the optic chiasm, it causes visual loss in both eyes. Compression of the inferonasal fibers that decussate at the anterior and inferior aspect of the chiasm leads to superior temporal heteronymous quadrantanopia. Continued growth can then lead to bitemporal heteronymous hemianopia. Another aspect discussed is that nonfunctioning tumors may account for up to 50% of adenomas, and many different patterns of visual loss can be shown. An additional discussion involved that patients with nonfunctioning tumors may present with symptoms of mass effect—headache, visual abnormality,

Table 1.

Learning Objectives for the Integrated Medical Neuroscience Course

Objective Number	Learning Objectives
1	Describe the cellular processes that are important in maintaining nervous system homeostasis
2	Explain the biochemical processes that are important in the integrated functioning of the nervous system in complex
3	Describe the development and structure of major components of the nervous system at the macroscopic, microscopic, and molecular levels
4	Correlate the structure of essential components of the nervous system to their physiological functions
5	Identify and correlate clinical gross anatomical features of the nervous system using common analytic and imaging modalities
6	Identify cross-sectional anatomical features of the nervous system
7	Correlate spatial relationships and orientation of anatomical features of the nervous system
8	Explain clinical observations following lesions of structures and functional pathways of the nervous system

nausea, papilledema, or hypopituitarism which may remain clinically silent for years. Thus, complex clinical concepts can be delivered alongside fundamental content to first-year medical students.

Description of Weekly Activities of the Medical Neuroscience Course

In the implementation of the course, traditional didactic teaching occurred between Monday and Thursday, and delivered contents were focused on clinically oriented materials. The objectives were provided so that students could use the information as a foundation for additional study, integrate the facts and concepts, and analyze neurological cases. In general, the medical neuroscience course had a total of 24 hours available for each week to implement all activities and is consistent with all courses taught in the first two years of medical school. This same amount of time was available for other courses. The distribution of curricular time for the course during the in-person learning was as follows: neuroanatomy laboratory (six hours/week; 25.0%), didactic teaching (18 hours/week; 75.0%). In addition, 8:00–10:00 AM on Fridays was used to integrate all the materials taught between Monday and Thursday using clinical cases.

Laboratory Learning of Neuroanatomy

The in-person neuroanatomy laboratory activities using cadaveric brain specimens, models, and medical imaging were the standard before Covid-19. During these laboratory sessions of the in-person learning, students worked in small groups of four students per group for a total of ten groups for two hours (2:00–4:00 PM) per session for three sessions (six hours) per week. Each group, together with their tutor, carried out guided whole-brain dissections. Plastic models and specimens are used by students to guide the dissection of the brain. Digital resources including magnetic resonance imaging (MRI) and associated software packages are used as a self-study prior to dissections. Prosections were also available for reviewing after each neuroanatomy laboratory session along with neuroscience faculty and fourth-year medical students (tutors) present to provide guidance and answer questions. During the review of the prosection, the instructor leads the students through requisite anatomical structures spending roughly 30–40 minutes for the review. This was done to help students understand each step of the brain dissection since they already did the dissection on their own. This step reinforces the content for a better understanding of the dissection processes and different subcortical structures in the sagittal and coronal planes. Mastery of this content was accessed using laboratory quizzes and a laboratory practical. As in-person instruction was not possible for the year 2020 cohort, students used the digital resources including computed tomography (CT) and MRI imaging as a self-study, and the in-person laboratory activity was replaced with the digital neuroanatomy software for the virtual dissection of the brain. In both, the in-person and blended learning, practical examinations were delivered with ExamSoft assessment software (ExamSoft Worldwide, Inc., Dallas, TX), and using primarily two-dimensional images. Other summative examinations were also delivered using the ExamSoft assessment platform. While the format of implementation varied, the assessment format remained identical for the in-person and blended learning approach.

Description of the Adaptive Blended Learning Activities

In general, the same schedules for the in-person learning were maintained in the adaptive blended learning, except that year 2020 medical students were allowed to work at their own pace for the neuroanatomy laboratory, which was scheduled for Wednesdays and Thursdays (three hours each day) during the in-person learning. In response to Covid-19, the entire integrated medical neuroscience course at the University of South Carolina School of Medicine-Greenville was quickly transitioned for implementation using the online format and digital technology that included all course contents including laboratory activities, clinical cases discussions, and lectures. An adaptive blended learning model was used that utilized online learning as a template in implementing an integrated medical neuroscience course. Digital technology was employed to facilitate live or virtual interaction of students with faculty members. This provided the leverage to implement all of the medical neuroscience activities carried out in the previous year, but also provided the opportunity for the medical students to control their time, place, path, and pace of learning neuroscience concepts. This approach was taken to give students the flexibility to deal with their own individual circumstances during the pandemic. The content, sessions, and volume of the materials were kept constant as in the previous years in the medical neuroscience curriculum. While this adjustment was challenging to the students, the decision was made not to eliminate some learning objectives or content because of the rescheduling of all activities using the adaptive blended learning approach. This approach was chosen to maintain the high standard expected required to prepare our students for the National Board of Medical Examiners (NBME) Step 1 Examination.

Neuroscience is among the most intellectually demanding of the basic science disciplines (Markram, 2013) in the first two years of medical education, whether the instruction is presented in-person or online. The expectations of the same level of excellence prevented diluting the material even though it was presented on line. The same volume and standards of instruction were maintained to ensure that students were adequately prepared to proceed in terms of their medical education. The same requirement of a strong academic preparation for any standardized examination was maintained, irrespective of whether the medical neuroscience course materials were taught online or in the in-person classroom setting. A major concern involved the implementation of a neuroanatomy laboratory that required the dissection of brain and identification of subcortical brain structures. To address this concern, "Digital Neuroanatomy" software was uploaded on the students' virtual laptops, and this was used by students in the neuroanatomy laboratory. If the course remained in person, the software would only have been installed in the computer network in the neuroanatomy laboratory, where it would allow students to work as a group to dissect the brain and identify cortical and subcortical structures in a small group setting.

"Digital Neuroanatomy" software (Leichnetz, 2006) was chosen because it provided neuroanatomical interactive virtual activities which shifted all the laboratory activities, contents, and instructions to the control of the student allowing each student to manage the pace of their study, with the ability to pause, go back, or skip forward through online content as desired during the implementation of the different activities. During the online activities, students were able to interact with several human brain dissections with the virtual brain, which

can be resized, rotated in all directions, and certain areas can be selected allowing students to identify structures of particular interest. Moreover, students could select the particular dissection of interest and view the brief animated gifs of the actual dissections which demonstrated how each virtual brain was prepared. Multiple learning formats were provided comprising written instructions, video tutorials, and demonstration of brain dissection, offering students a self-paced, interactive review of the structure and functions of the brain. In addition, formative practice questions were provided to help apply learned concepts to clinical application. In most cases, students chose the time at which the neuroscience laboratory activities were scheduled in remote locations. The didactic lectures were presented by the same faculty rather than using recordings of lectures given in previous years. The faculty appeared in person inside the empty lecture room. These didactic lectures were recorded on Panopto video platform, version 9.1 (Panopto, Inc., Pittsburgh, PA) and sent to students one hour at most after each lecture. The Panopto platform provided a unique media pipeline that used HTTP Live Streaming (HLS). This utilized an adaptive bitrate streaming communications protocol (Apple, Inc., Cupertino CA) for video capture and to provide live webcasting. This approach allowed faster video startup times, reduced buffering, unmatched scalability, and higher-quality playback for medical students. Giving lectures in an empty lecture room and not using previous year's recorded lectures gave the students a sense of presence and newness in the materials presented. Moreover, this provided the opportunity for students to actively interact in real-time with faculty members via the WebEx platform, version 4.0 (Webex Communications Inc., Milpitas, CA) which provided a simple user interface and combined the online viewing portion with the ability to teleconference, allowing students to interact with the faculty in real-time. All lectures were captured using Panopto platform which provided lecture recording, screencasting, video streaming, and video content management, and allowed playback, in an easy-to-use format. The ease of use of Panopto software is one of its main virtues. Lecture content recorded on Panopto platform was integrated into the Canvas management system, version 5.0 (Canvas Inc., Salt Lake City, UT) allowing online interactive discussions which helped generate information that was useful for real-time interventions. This provided a real-time response and communication with students in the adaptive blended learning environment. All students were provided Apple tablets, and there were no reports any of issues

in running the Digital neuroanatomy software. No other technical issues such as internet access were reported either.

In addition, the students were provided with practice questions, and with cases providing clinical examples of the disease entities discussed. Students in the Year 2019 class were able to ask questions during the class session. The requirements dictated by Covid-19 precluded student participation in class during the lecture or class session. However, students in the Year 2020 class were able to ask questions during the session on WebEx, and the faculty responded directly during their session. This approach was adopted to give the students virtual interactive sessions with the faculty giving the lecture. In general, for the Year 2020 class, students interacted with faculty members in real-time and also received the video one hour after the scheduled lecture. The students could then watch the video immediately or at any time desired. Student questions/comments were addressed in real-time, and later pooled together and posted with the video so that students could take more time to review the responses together with watching the video. For both the Years 2019 and 2020 classes, the students were provided with recordings on Panopto video platform. Students were also able to email the faculty with specific questions. The initial question, as well as the faculty member's response, were then circulated by email to the entire class. This practice was followed in the classes for both years studied. A summary of the structure of the face-to-face course and the blended online course with respect to content, delivery, and assessment is presented in Table 2.

Structure of Student Evaluations

The format of the laboratory quizzes involved the identification of surface anatomy and subcortical structures from structures identified using the neuroanatomy interactive software and the extensive use of clinical vignette-style questions similar to the format used by the National Board of Medical Examiners® (NBME®) Step 1 Examination. The clinical vignette questions accessed students in the clinical case discussion sessions that were recorded on Panopto platform and posted on the Canvas learning management system platform. The short length of the module (four weeks) meant that only one single summative examination was possible. The module was structured to include five laboratory quizzes (12%), clinical correlation/laboratory practical examination (36%), while the final summative examination contributed 52% of students' total grades. Remote proctoring for the final summative examination was conducted using ExamSoft, version 5.0 (ExamSoft Worldwide Inc., Dallas TX). The same vignette-style examination format for the laboratory quizzes was used for the final laboratory summative examination. The format for standard item evaluation including the item difficulty index and biserial values. The item difficulty index determined the proportion of examinees who answered a question correctly. For questions with one correct alternative that is valued at a single point, the item difficulty determines the percentage of students who answer a question correctly. In this case, it is also equal to the item mean. The item difficulty index value ranges from 0 to 100; the higher the value, the easier the question. When an alternative is worth other than a single point, or when there is more than one correct answer for a question, the item difficulty is the average score on that item divided by the highest number of points for any one alternative. Item difficulty accesses medical students' content mastery of the neuroscience concepts and helped to determine the ability of an item to discriminate between students who

Table 2.

The Structure of the Face-to-Face Course and the Blended Online Medical Neuroscience Course with Respect to Content, Delivery, and Assessment

Course Modality	Face-to-Face Course (2019)	Blended Online Course (2020)
Contents/ Activities	Laboratory activities, small group activities, didactic activities	Virtual laboratory and learning activities
Delivery	In-person laboratory or classroom activities	Digital technology (virtual interaction)
Assessment	Summative and formative assessments and weekly quizzes.	Summative and formative assessments and weekly quizzes

have learned material and those who do not. A low discrimination value would be obtained if the question is so difficult that almost every student gets it wrong or guesses, or is so easy that almost everyone answers correctly.

The validity and reliability of each of the assessment question were determined using the point biserial correlation. This revealed the correlation between the right/wrong scores that students receive on a particular question and the total scores that the students received when summing up their scores across the remaining questions. As with other all forms of correlations, the point-biserial values ranged between −1.0 and +1.0. A large positive point-biserial value was indicative of students with high scores on the overall test answered the question correctly, while those with low point-biserial values on the overall test are answering incorrectly. A low point-biserial indicated that students who answer a question correctly perform poorly on the overall test, while those students who answer incorrectly tend to do well on the test. The *P*-value of a particular question reveals the proportion of students that score the item correctly. When this is multiplied by 100, the *P*-value converts to a percentage, and this represented the percentage of students that answered the question correctly. The *P*-value statistic value ranged from 0 to 1 and was calculated for each of the test questions. These analytical tools evaluated the performance of the same questions used in Years 2019 and 2020 for the final summative examination, and the resulting average percentages were presented for both years. Internal consistency was determined using the KR-20 (Kuder–Richardson Formula 20) which is an index of the internal consistency reliability (Saupe, 1961). The test provided information about the reliability of each of the four formative examinations in providing a challenge and encouraging more profound levels of learning and preparing students for the final summative examination. The formative assessments did not contribute to the total points available to students in their final grades. These four formative examinations were provided throughout the four weeks of the module. The assessment was in the form of weekly quizzes that included materials from the class discussions and laboratory activities. The quizzes were available for students from 12:00 noon Thursday to 12:00 AM on Saturday. They were more designed to be challenging to encourage deeper levels of learning, and to reflect the format and difficulty anticipated for the summative assessments. In terms of the feedback to improve student performance, the formatives allowed the students to test their knowledge of the material. These "practice" questions give additional opportunities not only to test students' understanding of the material, but gives them an opportunity to become familiar with the style of questions used by each faculty member. Review sessions were scheduled to assist the students to improve their scholarship. Moreover, an active tutoring and mentoring program has been available at USC-Greenville, particularly to those encountering academic difficulty even during the pandemic.

Summative assessments were designed to access medical knowledge, understanding, and application of neuroscience concepts and principles to clinical problem-solving. The format consisted of clinical vignette questions. Structures identified in the virtual laboratory activities were linked to clinical cases during the clinical case session. This approach allowed students to apply, analyze, synthesize and evaluate facts and concepts, and develop competence in clinical reasoning and critical thinking. Summative laboratory practical quizzes and examination included questions spread over five laboratory activities. The final summative written examination included questions drawn from the anatomy, embryology, physiology, biochemistry, histology, and neuropharmacology of the nervous system.

Data Analysis

The overall performance of students for the summative examination for the two years was determined. The reliability of the examination was determined using the KR-20 (Kuder–Richardson Formula 20), which is an index of internal consistency and reliability (Saupe, 1961). Values for KR-20 generally ranged from 0.0 to 1.0, with higher values representing a more reliable test capability of discriminating between students who had a higher understanding of the test material versus those with a poorer understanding. A KR-20 value of 0.5 or higher is a good threshold value for determining whether or not a test is reliable (Zimmerman and Burkheimer, 1968).

All summative questions were mapped to each of the course level objectives.

Statistical comparisons were determined for in-person versus adaptive blended learning for assessments. Normality (i.e., parametric vs. nonparametric) for all data was determined using the Shapiro–Wilk test and box plots. Continuous variables that did not meet parametric standards were log-transformed to reduce the skewness of the data. Descriptive analysis was determined using proportions (e.g., percentage) for categorical variables, while mean and standard deviation were used for continuous variables. The mean percentage of performances for each of the module level objectives was computed for the Year 2019 during in-person teaching and compared with the Year 2020 of the adaptive blended online learning of all the materials.

To determine the significance of differences between the Year 2019 and Year 2020 for the final summative examinations, the Student's *t* test (two-tailed) was considered. This analysis enabled us to compare differences in means for the performance scores between adaptive blended learning and in-person learning of materials. Because students' performance spread between 70–79, 80–89, and >90 for both classes, ANOVA with repeated measures or within-subject was utilized. Using the ANOVA enabled us to make broad comparisons for examination takers and their percentage performances for 70–79, 80–89, and >90 (90–99) categories for both classes. Post hoc analysis was used to determine significant differences between the performance categories for Years 2019 and 2020. Statistical significance was established at $P < 0.05$. All statistical analyses were performed utilizing SPSS statistical package, version 25.0 (IBM Corp, Armonk, NY).

RESULTS

The results for the reliability analysis of the formative and summative examinations administered for the 2019 and 2020 classes have been tabulated (Table 3). KR-20 values for the formative examinations ranged between 0.19 and 0.90 for the Year 2019, and 0.58 and 0.88 for the Year 2020. The value for the summative examination was 0.85 for the Year 2019 and 0.83 for the Year 2020, indicating the reliability of the summative examinations for the adaptive blended learning session and for the in-person class activities. The reliability value for KR-20 was low (0.19) for the Year 2019 when compared with the Year 2020, as only 20% of the students took formative 4 compared with 80% in the Year 2020. The lower performance is reflected in the low participation, as more than

70% of students participated in all formative examinations for both years apart from formative 4 in the Year 2019. The different analytical tools including the item difficulty index and point biserial index evaluated the performance of test questions and the resulting average percentages for both years (Fig. 1). Both the item difficulty index and point biserial index analytical tools showed high discrimination for test questions for the summative examinations for both years. Students' performance for each of the course objectives compared between Years 2019 and 2020 is presented in Figure 2. A direct comparison using a two-tailed, paired Student's t test reveals that the performance in objectives 1, 2, 3, 4, 6, 7, and 8 were not significantly different between Year 2019 and Year 2020 ($P > 0.05$ for objective 5 ($P < 0.05$). A two-tailed test also indicated that the performance in Year 2019 ($M = 86.08$, SD ±0.11) and Year 2020 ($M = 86.07$, SD ±0.55), $t(101) = 0.18$, $P < 0.05$) were not significantly different. Student performance for the different grade categories for 70–79, 80–89, and >90 is presented in Figure 3. ANOVA with repeated measures found a significant difference among students in the different performance categories between 70–79, 80–89, and >90 [$F (2,114) = 7.154$, $P = 0.0401$]. Post hoc analysis revealed a significant difference ($P < 0.05$) among student performance for 70–79 ($P < 0.05$) and 80–89 ($P < 0.05$), but there was no significant difference ($P > 0.05$) for the >90 category in both Years 2019 and 2020.

DISCUSSION

This was one of the first studies to assess the differences in in-person and blended learning as delivery methods for an integrated neuroscience science course before and during the Covid-19 pandemic. It delineates how anatomy educators retooled to implement an entirely new way of delivering a first-year medical student neuroscience course online. Pre-pandemic, in-person cadaveric dissection was considered obligate. Due to the extraordinary circumstances of the pandemic, virtual neuroanatomy laboratory activities were developed using digital neuroanatomy resources and communication tools to teach neuroanatomy during the Covid-19 pandemic. Prominent changes were made in laboratory delivery methods during Covid-19, with the elimination of in-person cadaver-based dissection along with significant increases in the use of digital software for the virtual dissection of the brain.

Regardless of whether the course was taught in-person or through blended learning, the reliability of the test items were generally high for Years 2020 and 2019, indicating the reliability of the summative examinations for the adaptive blended learning when all activities were delivered virtually, and the in-person class activities of traditional "brick-and-mortar" learning. Moreover, the high values for both years indicate the likelihood of obtaining similar results if the examinations are administered to another group of year one medical students using questions administered for Years 2019 and 2020. The high discrimination for test questions for the summative examination detected by item difficulty index and point biserial index corroborates an earlier report (Attali and Frankel, 2000) of high discrimination in analytical indices provided a mechanism for validating questions and testing the performances of same questions (Chiavaroli and Familari, 2011) used in the Years 2019 and 2020 examinations. Students' performance was not significantly different from student performance on the summative examination for all objectives and was not significantly different for both the adaptive blended learning and in-person learning except for objective five, where a higher performance was recorded for the in-person learning method. In objective five, students were expected to identify and correlate clinical gross anatomical features of the nervous system using common analytic and imaging modalities. Students who experienced in-person learning, the 2019 cohort, did score higher when compared to the 2020 cohort who had blended online learning, where such small group activities were not implemented. The clinical case discussion sessions provide an interactive platform that allowed medical students to thoroughly analyze spatial, cross-sectional features and neural pathways of the nervous system from an integrative perspective. These types of sessions have been reported to improve student performance (Greenwald and Quitadamo, 2014; Shaffer, 2016). Before Covid-19, objective 5 was mainly implemented in small group activities where students interacted with each other to analyze neurological cases. Therefore, this objective supports a constructive alignment (Biggs, 2014) in which medical students know what to learn, and how their learning will be implemented was clearly stated before the implementation of the objective. A student-centered learning activity was designed for objective 5,

Table 3.

Class Performance on Each Week's Formative and the Final Summative Assessments in the Integrated Medical Neuroscience Course

Assessments	Year 2019 Mean % (± SEM)	Year 2020 Mean % (± SEM)	P-Value	Year 2019 KR 20	Year 2020 KR 20
Formative 1	75.66 (± 1.22)	89.32 (± 1.41)	<0.05	0.69	0.85
Formative 2	68.52 (± 1.14)	70.48 (± 1.16)	>0.05	0.90	0.88
Formative 3	70.09 (± 1.15)	72.04 (± 1.18)	>0.05	0.82	0.78
Formative 4	84.58 (± 1.27)	88.12 (± 1.35)	<0.05	0.19	0.58
Summative	86.08 (± 1.30)	86.07 (± 1.30)	>0.05	0.85	0.83

The table presents Kuder–Richardson Formula 20 (KR-20) tests for the reliability of the assessments. The formative examinations had KR-20 values that range between 0.19 and 0.90 for the Year 2019, and 0.58 and 0.88 for the Year 2020. The scores for both years were high and indicate the strong reliability of the formative and summative assessments. For the formative assessment, the last KR-20 for the week 4 formative examination was low and reflects the difficulty of the test items. An average of 77 and 79 students participated in the formative examination in the year 2019 and 2020, respectively, for all the eight objectives of the neuroscience course. SEM, standard error of the mean.
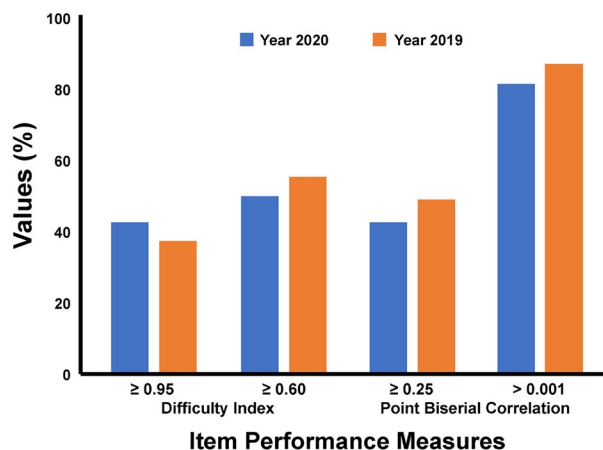
Figure 1.

Item performance measures (difficulty index and point biserial correlation) for summative questions during the in-person (Year 2019) and the adaptive blended learning sessions (Year 2020). The item difficulty identified the percentage of students who answer a question correctly. In this case, it is also equal to the item mean. The item difficulty index value ranges from 0 to 100; the higher the value, the easier the question. The point biserial correlation was used to determine whether a test question is likely to be valid and reliable. The point-biserial values ranged between –1.0 to +1.0. A large positive point-biserial value revealed that students with high scores on the overall test answered the question correctly, while those with low scores on the overall test are answering incorrectly. A low point-biserial indicated that students who answer a question correctly perform poorly on the overall test, while those students who answer incorrectly tend to do well on the test.

and the expectation was that such a learning environment would raise medical students' motivational level and stimulate critical thinking (Brechtel et al., 2018) to go beyond facts and details in correlating clinical gross anatomical features of the nervous system using common analytic and imaging modalities and clinical cases. A possible explanation for the higher performance of objective 5 in the Year 2019 during the in-person is that the small group collaborative learning activities for this objective recognized the value of cognitive interaction with teachers and peers, and promoted the exchange and participation of students and teachers in order to build a shared cognition (Roselli, 2016). The collaborative learning experience in the implementation of objective five probably represented a construct that enhances learning both in face-to-face and virtual education, and may be significant in the future of the blended learning approach to optimize the effect of blended learning activities.

More students scored between 70% and 79% in the adaptive blended learning when compared with in-person learning, indicating that the medical neuroscience course presented by means of adaptive blended learning activities can be used for the early identification of underachieving students and may serve as an early warning sign for timely intervention before the students move on to their next course. It is also possible that the adaptive blended learning format was not very helpful for average performing students as more students scored between 80% and 89% in the Year 2019 when compared with the Year 2020. Our findings align with a recent study by Herr and Nelson (2021) that reported a lower performance on the written examination. Moreover, the collaborative learning activities in 2019 potentially enhanced learning for average students during the in-person activities when compared with virtual education with blended learning.

There are many benefits of in-person learning (Sugand et al., 2010) that may be lost in a remote learning setting (Attardi et al., 2016, 2018). Since the option of providing an in-person neuroanatomy laboratory component of the medical neuroscience course was seriously affected due to the pandemic, an alternative pedagogy had to be considered. An adaptive blended approach that focused on digital technology was an immediate option, considering that medical students are proficient in using digital technology (Marchevsky et al., 2003). While medical students are proficient in using digital technology in an integrated medical curriculum, it is also important to point out that success in using digital technology also depends on students' access to that technology, especially during this pandemic. This may disproportionately affect those students without such access, creating inequalities during the pandemic that may affect their performance. This disparity has been reported during the Covid-19 pandemic in many educational settings, where students that do not have reliable access to stable internet connections are struggling (Dhawan, 2020). A primary concern involved meeting the needs of students, while also meeting the requirements imposed by the responses to Covid-19. A primary concern involved attempting to find a creative solution that would use technology to produce the same results as the classroom lecture experience. Another factor involved the provision of Apple tablets to the students, standardizing the technical resources available to all students. Thus, it is important that all students were given Apple iPad Pro 4th generation model (Apple Inc., Cupertino, CA) when they matriculated. This was available for students in Years 2019 and 2020. This alleviated any concerns about variations in technology available to the members of the class during the pandemic. Moreover, anatomy digital resources were available for the virtual neuroanatomy dissection and provided three-dimensional (3D) models of neuroanatomy (e.g., complete brain dissection) or actual cadaveric brain images. This approach is supported by Longhurst et al. (2020) and Pather et al. (2020) in increasing the availability of anatomical digital resources for students during the pandemic.

A major feature of this adaptive blended learning approach is that it enabled medical students to utilize an individually customized, fluid schedule with respect to their learning activities. This format is supported by other studies (Green and Whitburn, 2016; Gurung et al., 2016; Hernández and Ramírez, 2016; Green et al., 2018) and was probably helpful for high-performing students resulting in a statistically non-significant difference in students scoring >90 in the Year 2019 of the in-person learning when compared with the Year 2020 of the adaptive blended learning pedagogy. Since the overall class means did not differ from 2019 to 2020, the observed differences in the percentile groupings may simply be a result of normal yearly variation in the habits of an incoming class, that is, some students in the 2019 class may simply have worked harder than the students in the 2020 group. It is important to point out that the stay-at-home orders for the pandemic occurred the day prior to the implementation of the 2020 medical neuroscience course, so there is a tendency for elevated stress and anxiety in these students compared to previous years. However, the overall performance did not change especially for the high-performing students. The absence of a statistically significant difference between the two classes revealed that this approach was generally effective. One could hypothesize that the fact that there were some differences in the lower end of the grade scale might be explained at least in part by the absence of student interactions with each other during the instructional sessions. Learning online is an intrinsically lonely experience (Attardi
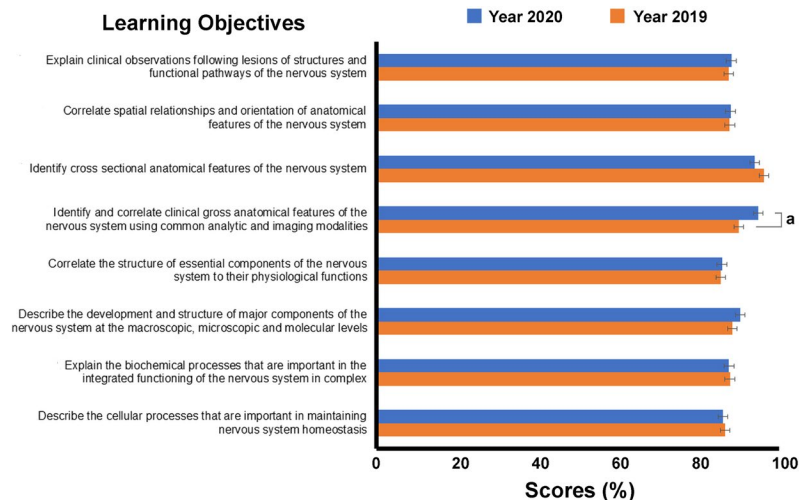
Figure 2.

Percentage mean scores achieved on the summative examinations for each of the eight learning objectives in the Neuroscience course. Number of medical students in the Year 2019 during the blended learning activities compared with the Year 2020 adaptive flexible blended learning of all materials online ($n = 102$); [a]$P < 0.05$.

et al., 2018), and many benefits associated with in-person learning especially in neuroanatomy laboratory-based learning are difficult to simulate remotely and may lead to undesirable responses by some students as it is commonly assumed that in-person learning anatomy or cadaver laboratory is a rite of passage (Chiou et al., 2017) and a special privilege for students (Attardi et al., 2016). Digital learning, particularly 3D animated models, may present unique pedagogical challenges. For example, many user controls may allow for the manipulation of the models in different ways, and the software learning curve can be sharp, such that training interrupts the time required to learn anatomy (Attardi et al., 2016). Moreover, studies of remote learning in anatomy indicated that in-person learning enabled students and teachers to be more engaged, making communication easier compared to remote learning (Attardi, 2018). Collectively, in our current study, students who are very intellectually oriented may have done better (without or without in-person anatomy experience) than those of a more social nature who may have had difficulty in maintaining concentration and determination under these circumstances.

Digital technology was the cornerstone of this adaptive blended learning model for the implementation of a medical neuroscience course during the time of a pandemic. This fully integrated platform for delivering academic instruction enabled medical students to operate independently and receive help from neuroscience faculty in implementing different active learning activities. The WebEx and Panopto platforms were effective for the virtual interaction involved in discussing clinical cases. This was useful in providing clinical relevance to foundational neuroscience concepts. Students were provided with newly recorded lectures on Panopto platform that provided asynchronous delivery of learning materials, not only to keep medical students engaged, but also to provide a sense of newness in the presented materials.

Although medical students operated independently, they received help from faculty through email communication and from the online interactive discussion platform on Canvas.

In addition, live sessions with WebEx permitted for real-time communication, as well as multiple interactions on Canvas. Therefore, the Canvas and WebEx platform proved effective for a focused, group-interactive, discussion of each session and in tracking the students' activities and progress in their understanding of the course content. While medical students that are trained in an integrated medical curriculum are experienced in following the curriculum online and using digital technology (Jameson et al., 1996; Marchevsky et al., 2003; McCutcheon et al., 2015), they are also accustomed to self-study and working independently at their own pace (Brechtel et al., 2018, 2019). The ease with which medical students navigate digital technology-based learning, along with the independence they have developed in an integrated medical curriculum made the transition to blended learning may have made their translation a little less stressful. This fits well with the adaptive blended learning approach, especially for high-performing students.

While a pandemic can temporarily disable the "bricks" component of blended learning, medical students are already adapted to both synchronous and asynchronous styles of learning (Bandla et al., 2012; Vo et al., 2019; Moszkowicz et al., 2020), giving them a unique advantage in an adaptive blended learning pedagogy. The same is true for neuroscience faculty members who have extensive experience in implementing an integrated medical curriculum for many years by combining digital technology with online activities. All the needed lecture materials, active learning activities, and discussion of clinical cases were implemented in real-time using a combined WebEx and Panopto platform. While it is possible to increase the efficiency of blended learning, this will require more faculty involvement and robust digital technology to enhance interactive virtual activities with students (Attardi et al., 2018). It is also important to point out that we did not simply record lectures and did not use lectures recorded in previous years. Instead, faculty appeared in-person inside the empty lecture room and presented didactic lectures which were recorded on Panopto platform and sent to students one hour at most after
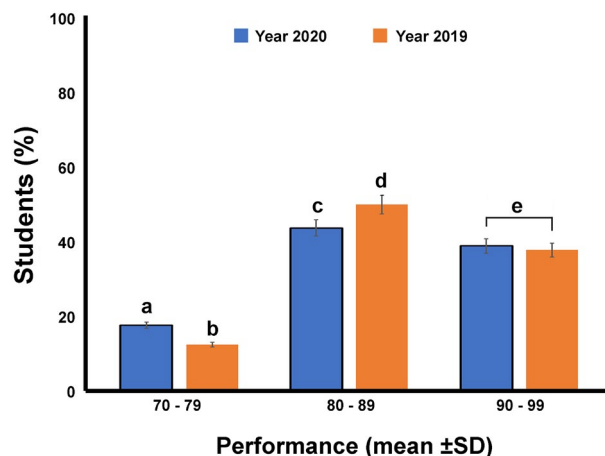
Figure 3.

Students' performance (mean ± SD) in grade categories for 70–79, 80–89 and >90 for years 2019 and 2020 ($n = 102$). Differences between students of different grade levels were determined with one-way ANOVA with repeated measures for all variables with homogenous variance across groups. Post hoc analysis for all significant differences found different student grade levels. Bars with the same alphabets are not significantly different, but different from bars with different alphabets are significant ($P < 0.05$).

neuroscience course materials and their capability for virtual interactive activities. This includes using WebEx, Panopto or Canvas platforms for interactive discussion and connecting with peers and teaching neuroscience faculty members. In this context, the adaptive learning model not only helped to generate individualized learning materials that helped medical students to improve mastery of learning neuroscience materials, but it also helped to virtually connect students with faculty members. This was very helpful for faculty members, enabling them to interact with medical students at a deeper level to address students' concerns and facilitate their learning process.

Finally, this adaptive blended learning provided an adaptive environment of an individualized learning experience combined with digital technology capabilities that focused on medical student strengths to enhance faculty–students interactions, and student-content interactions. Therefore, the adaptive blended learning model utilized in this study recognized the strengths of medical students and ensured that learning materials are learner-specific, while the personalized and adaptive learning environment helped individual medical students to better meet their competency requirements in learning the content materials of the neuroscience laboratory activities during this pandemic.

Limitations of the Study

There are limitations to this study. Data on students' performance were collected for adaptive blended and compared with in-person learning in a medical neuroscience course taught during the pandemic. While this study represents an important time point in medical neuroscience education, future studies are necessary to determine whether the effect of blended learning on medical students' performance characterized in this study are Covid-19-related shifts or if the findings represent a long-term change in the delivery of an integrated medical neuroscience course. Qualitative and quantitative data on the proportion of the students viewing the Panopto-recorded lecture in real time and their satisfaction were not available. Future studies on such data will reveal whether this approach was preferred by students compared to viewing a previously recorded lecture, and their satisfaction with the in-person and blended learning approach. The focus of this study was on virtual neuroanatomy laboratory activities within the neuroscience course taught virtually, therefore, not all academic programs may be reflected in the data (e.g., physiology, histology, etc.). This study describes how a medical neuroscience course was implemented using an adaptive blended pedagogy and the effect of the pedagogy on student outcomes and compared data with an in-person learning approach. In the future, the authors of this study plan to characterize the early teaching adaptations following the onset of Covid-19 and determine how changes in lecture and laboratory delivery methods and assessment methods affect neuroanatomy education during Covid-19 pandemic.

CONCLUSIONS

This study has described the development of an adaptive blended learning pedagogy that combined digital technology to provide virtual or live interaction and blended this with online student activities. While the adaptive blended learning was effective in the early identification of underachieving students serving as an early warning sign for timely intervention, the format was very effective for high-performing medical students.

each lecture. It was well reasoned that giving lectures in an empty lecture room and not using previous year's recorded lectures gave the students a sense of presence and newness in the materials presented. Remote learning, relied on different forms of software, and Zoom streaming platform (Zoom Video Communications, Inc., San Jose, CA), has been the most dominant and most commonly used in the academic environment (Pelosi, 2016). In the current study, the WebEx platform provided a simple user interface allowing chatting with students in real-time. In addition, Panopto video platform provided lecture recording, screencasting, video streaming, and video content management, and allowed playback functions. Moreover, it was easy to use, which was important so that the students did not have to master a new technique. Panopto platform was integrated into the Canvas platform, allowing online interactive discussion which helped generate information that was useful for real-time intervention. This provided a real-time response and communication with students in the adaptive blended learning environment. Finally, students' questions/comments were addressed in real-time, and later pooled together and posted with the recorded video so that students could take more time to review the responses in line with the posted watched video. In general, the use of this fully integrated platform for delivering academic instruction for a medical school curriculum meant that students and faculty members had all the resources necessary for the implementation of an adaptive blended learning method that systematically blended virtual interaction with online activities for the implementation of a medical neuroscience course in a time of the pandemic.

This adaptive learning model is not just restricted to considering the contents of materials to medical students based on their particular learning needs of medical neuroscience contents for their future medical career. Other forms of adaptation were considered, including adaptive digital technology where medical students can easily navigate the structure of the

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